Cutting-edge technologies sustainability assessment towards EC Digital Decade 2030 Compass objectives

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Abstract—In 2022, the EC Digital Decade 2030 Compass identified seven cutting-edge digital technologies, the development of which will receive special attention in the coming years. Digital technologies are a specific type of technology that is critical to the existence of today's society. Failures in technological development can have fatal consequences, so assessing the sustainability of digital technologies is a very important task.

The aim of the study is to assess the sustainability and potential risks of development of the proposed cutting-edge digital technologies.

Two-level Integrated Acceptance and Sustainability Assessment Model (IASAM) is used to assess sustainability, where digital technology acceptance and sustainability assessment is first performed using system dynamics simulation and Skype reference line modulation to calculate the sustainability index. Subsequently, Bayesian acyclic networks are used to assess potential risks. The simulation results indicate the potential sustainability risks of some of the digital technologies and industries mentioned in the EC Digital Decade 2030 Compass.

The article can be useful for digital sustainability researchers, investors and new digital technology developers.

Keywords—Digital technology, systems sustainability, system dynamics simulation, IASAM model, sustainability risks assessment, Digital Decade 2030.

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1. Introduction

THE European Commission's (EC) Digital Decade 2030 report set out basic guidelines for the further development of digital technologies [1]. The guidelines form a multi-level pyramid (see Fig. 1), the highest level of which defines activities aimed at the development of democracy, which contain a high proportion of the digital component.

For example, the priority of human resources, solidarity and inclusion, freedom of choice, e-participation, safety and security, and Sustainability $(S_{T}j)$ as well. These democracy-building activities are based on a heterogeneous set of digital services, such as artificial intelligence, data governance, data spaces, online platforms, cybersecurity and media pluralism. In turn, these digital services will be provided by the purposeful development of specific cutting-edge technologies. Document [1] identifies seven digital technologies: Digital Twins (T^7), High-Performance Computing (T^6), Digital Wallet (T^5), Quantum Computing (T^4), Microelectronics (T^3), Blockchain (T^2) and 5G Communication (T^1).

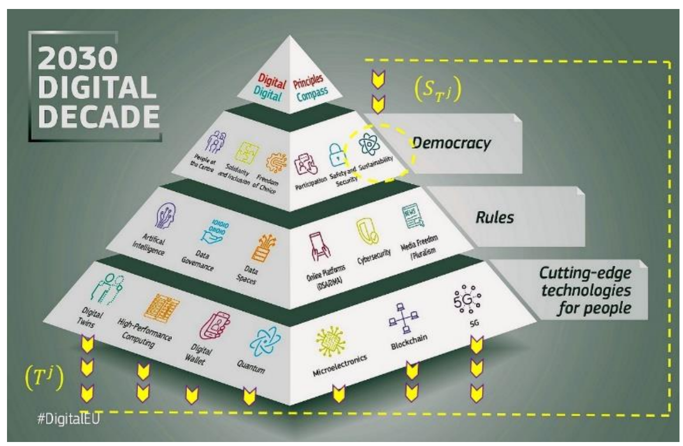

Fig. 1 EC 2030 Digital Decade (Digital Compass) ([1] modified by authors)

The specific concept is contradictory and ambiguous. For example, in 2021 Augmented and Virtual Reality (AR/VR) combined use with Robotics (RPA) were promoted as the top emerging technologies [2]. At present, the above technologies are no longer mentioned in the Digital Compass 2030 guidelines. Have the goals been achieved then? Of course not.

It is not clear by what criteria Artificial Intelligence (AI) is included in Digital Compass 2030 at a higher level of hierarchy than Digital Twins. It should be the opposite, as AI usually serves as a component of Digital Twins rather than the other way around. Why is Digital Twins included in this pyramid at all, because from a modelling point of view this is traditional method, rather than technology, has been used for decades? The essence of Digital Twins is to test the possible follow-up using asynchronously or synchronously modelling or simulation of a problem. That is, it is a daily practice in making any important decisions. Perhaps that the reason for the inclusion of Digital Twins in the Digital Decade 2030 pyramid is the ignorance of model-based decision-making approach at the level of policy crafters [3].

Why are both High-Performance Computing and Quantum Computing emphasized as supported technologies? Perhaps that the aim is to accelerate the development of Quantum Computing, which has been waiting on the Gartner curve [4] for more than a decade without real success.

Another important problem is the incomparability of the nominated cutting-edge technologies. It is not possible to build a pyramid of regular size, including blocks of different sizes on one level, at least the ancient Egyptians did not.

The authors [5], based on the Dijkstra hierarchical layers approach, identified the features of the core digital technology, and in particular:

1) Self-sufficiency - the technology is considered to be used independently.
2) Problem-orientation - the technology has a specific problem-oriented use.
3) Integrability - the technology can be used to create other technologies, complementing the newly created goal technology with a set of attributes belonging to the underlying technology.

The above classification is necessary to identify groups of core technologies that could be more or less comparable to identify hidden and unanticipated factors influences, which will significantly affect the risks of further development of cutting-edge technologies [5].

Based on the above criteria, 5G Communication, Digital Wallet and also Blockchain technologies can be considered to meet the characteristics of a digital core technology. However, the use of Digital Twins, High-Performance Computing and Quantum Computing is too general. Microelectronics is the basement of any digital technology. Microchip is part of any digital device, but it is not self-sufficient. Microelectronics can be considered an industry, but its nomination for cutting-edge technology could be challenging.

According to the hierarchical model of Digital Decade 2030 Compass (see Fig. 1), sustainability of technologies is at the same time a precondition for the sustainability of the development of democracy in society. Despite the fact that the conceptual model of Digital Decade 2030 is debatable, the aim of the article is to assess the sustainability of the cutting-edge technologies included in it, in order to understand the reliability of the digital development directions set by the EC. Using the system dynamics simulation-based IASAM methodology [6], the sustainability forecasts of the technologies included in the first level of the conceptual Digital Compass 2030 model will be assessed, but the potential risks of sustainability development will be predicted later.

The results of the study may be useful for researchers of sustainability, policy makers, as well as technology developers and investors who want to assess their future prospects *a priori*.

2. Sustainability Development and Risks Assessment of Cutting-Edge Technologies

The global dominant approach to sustainability assessment is based on the Triple Bottom Line (TBL) model, which identifies the potential impact of a product / technology on society, business and the environment. There are more than a hundred different sustainability assessment methods, mainly used to assess a variety of large projects with significant environmental impacts [5]. These methods are based on labour-intensive surveys of third parties / experts, usually ignore technology acceptance and adoption phases, and are difficult to adapt to assess the sustainability of other projects.

Because engineers and investors need faster and cheaper sustainability prediction that provide self-assessment capabilities, the authors [6] have developed and validated the IASAM model, which is based on systems dynamics simulation and Roger diffusion theory. Sustainability is assumed to be characterized by the interaction of four impact streams, which is modulated by the Skype reference curve. The sustainability index of technology $S_{Tj}(t)$ is measured in *skype* units, which provides good perception and interpretation possibilities:

$$S_{Tj}(t) = S_{Tj}(t-dt) + \left(Accept._{Tj} + Manag._{Tj} + Quality_{Tj} + Domain_{Tj}\right) * dt \qquad (1)$$

where:

1) $Accept._{Tj}$ – technology acceptance flow, which characterizes the society's desire to use the goal technology.
2) $Manag._{Tj}$ – management factors flow, which describes the resources available for technology development, implementation and maintenance.
3) $Quality_{Tj}$ – quality flow, which characterizes the essence and specifics of technology.
4) $Domain_{Tj}$ – external factors flow, representing market position, political factors, competitive aspects and other relevant parameters that may affect the sustainability of the technology / project / product.

The peculiarity of the IASAM method is the assessment of the sustainability index by analysing the impact of technology on society. Studies [5] have shown that the inclusion of the business and environmental pillars in the model is not useful in assessing the sustainability of digital technologies. This does not mean that digital technology has no impact on business or the environment. Of course, such effects do exist, but their importance is insignificant compared to the impact of digital technology on society. The impact of digital technology on the other two pillars is implicitly respected in the IASAM model.

Respecting the paradigm set out in the EC 2030 Digital Decade Compass [1] and the objections mentioned in the previous section, seven cutting-edge technologies $(T^j), j\epsilon[1,7]$, were evaluated by IASAM implementing a self-assessment of sustainability (see Table I).

2.1 Initial Conditions

During the self-assessment, it is assumed that all four impact streams that determine the sustainability index have the same weight. All factors that determine each flow of influence have the same weight. The result of the evaluation is a trend towards sustainability, which is a comparative perspective for the development of each technology in the future. The result of the flow estimation in absolute values is done according to the Likert 7-point scale. The interpretation of the value of the sustainability index is performed in accordance with the breakdown of sustainability groups set by the IASAM. Sustainability self-assessment reliability is not statistically validated.

2.2 Results

I. Cutting-edge technologies sustainability index (S_{T^j}) (*skypes*)

Item (T^j)	Management (*% of max*)	Quality (*% of max*)	Domain (*% of max*)	Acceptance (*% of max*)	Sustainability index (S_{T^j}) (*skypes*)
T^1 – 5G Communication	80	68	76	89	0.78
T^2 – Blockchain	84	73	74	74	0.76
T^3 – Microelectronics	79	57	90	58	0.70
T^4 – Quantum Computing	67	46	75	49	0.59
T^5 – Digital Wallet	84	74	73	79	0.77
T^6 – High-Performance Computing	82	61	86	66	0.73
T^7 – Digital Twins	82	73	86	76	0.79

A comparative graphical representation is shown in Fig. 2 and Fig. 3.

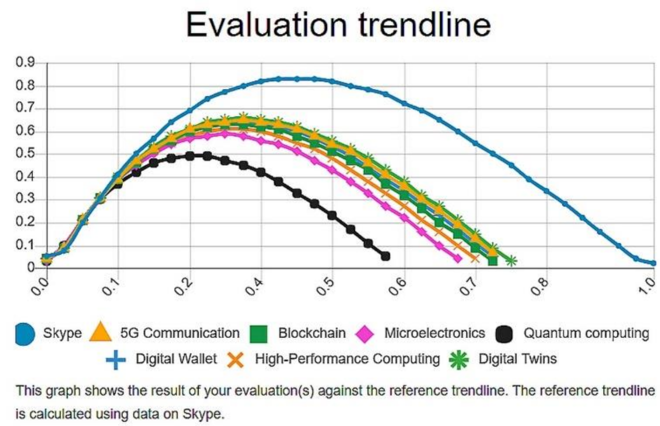

Fig. 2 Cutting-edge technologies sustainability development assessment

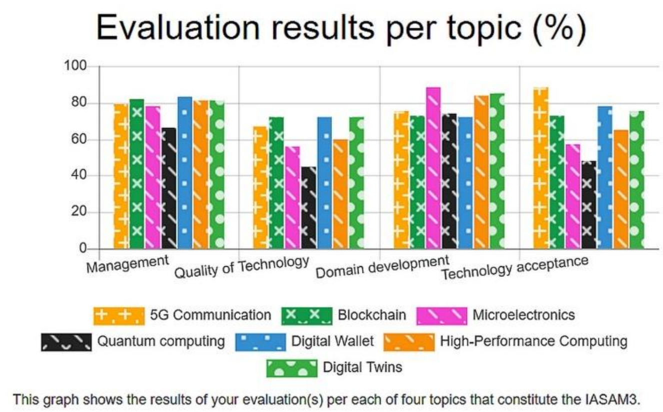

Fig. 3 Comparative representation of influencing flows

Assessing the risks to the sustainability development of technology is very important.

Digital technologies are a specific type of technology with a high stochastic component and are determined by unanticipated and hidden factors. This means that the sustainability forecast $S_{T^j}(t)$ requires a risk adjustment $\Delta S_{T^j}(t)$:

$$S_{T^j}(t) = S_{T^j}(t-1) * \Delta S_{T^j}(t). \quad (2)$$

The authors [5] have developed a Bayesian network model for assessing the risks to the sustainability of digital core technologies in the BayesFusion [7] GeNIe environment, which identifies the following main groups of hidden and unanticipated factors (F_T^U) that determine uncertainty of digital core technology:

$$(F_T^U) \sim \langle F_{TDI}^U, F_{TUE}^U, F_{TAF}^U, F_{TSD}^U, F_{TUU}^U, F_{TUC}^U, F_{TDU}^U, F_{TI}^U \rangle, \quad (3)$$

where F_{TDI}^U - determined and systematic impacts; F_{TUE}^U - unexpected stochastic externalities; F_{TAF}^U - the age dynamics factor; F_{TSD}^U - technology self-development possibilities; F_{TUU}^U - unexpected use; F_{TUC}^U - unanticipated consequences; F_{TDU}^U - dual-use possibilities; and F_{TI}^U - emerging incentives.

In the factor interaction model (see Fig. 4), it is assumed that the correction of the sustainability forecast ΔS_{T^j} and at the same time the total uncertainty attribute $A_{T^j}^{U^{FIN}}$ of the technology (T^j) corresponds to $F_{T^{UC}}^{U}$.

The influence of the network of factors (F_T^U) on uncertainty attribute $P\left(A_{T^j}^{U^{FIN}} \middle| F_{T^{UC}}^{U}\right)$ is characterized by (4):

$$P\left(A_{T^j}^{U^{FIN}} \middle| F_{T^{UC}}^{U}\right) = P\left(A_{T^j}^{U^{FIN}}, F_{T^{DI}}^{U}, F_{T^{DU}}^{U}, F_{T^{I}}^{U}, F_{T^{SD}}^{U}, F_{T^{UC}}^{U}, F_{T^{AF}}^{U}, F_{T^{UU}}^{U}, F_{T^{UE}}^{U}\right) / [P\left(F_{T^{DI}}^{U} \middle| F_{T^{DU}}^{U}, F_{T^{I}}^{U}, F_{T^{SD}}^{U}, F_{T^{AF}}^{U}\right) * P\left(F_{T^{DU}}^{U} \middle| F_{T^{UE}}^{U}, F_{T^{SD}}^{U}, F_{T^{I}}^{U}\right) * P\left(F_{T^{I}}^{U} \middle| F_{T^{SD}}^{U}\right) * P\left(F_{T^{SD}}^{U}\right) * P\left(F_{T^{UC}}^{U} \middle| F_{T^{DU}}^{U}, F_{T^{DI}}^{U}, F_{T^{SD}}^{U}, F_{T^{UU}}^{U}, F_{T^{UE}}^{U}\right) * P\left(F_{T^{UU}}^{U} \middle| F_{T^{SD}}^{U}, F_{T^{DI}}^{U}, F_{T^{UE}}^{U}, F_{T^{UU}}^{U}\right) * P\left(F_{T^{AF}}^{U} \middle| F_{T^{I}}^{U}, F_{T^{UE}}^{U}\right) * P\left(F_{T^{UE}}^{U}\right)] \quad (4)$$

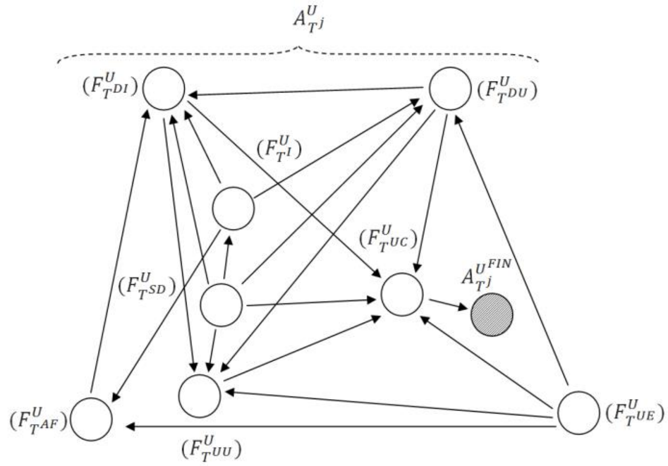

Fig. 4 Bayesian network of digital technology sustainability assessment risks

Based on (4) and [7], it is possible to perform cutting-edge digital technologies (T^j) unanticipated risks self-assessment $A_{T^j}^{U^{FIN}}$ (see Table II), which practically reflects the reliability of sustainability forecast ΔS_{T^j}.

II. Reliability of cutting-edge technologies sustainability forecast ΔS_{T^j}

Item (T^j)	Evidence							Sustainability risks $(A_{T^j}^{U^{FIN}} \sim F_{T^{UC}}^{U})$
	$F_{T^{DI}}^{U}$	$F_{T^{DU}}^{U}$	$F_{T^{I}}^{U}$	$F_{T^{SD}}^{U}$	$F_{T^{AF}}^{U}$	$F_{T^{UU}}^{U}$	$F_{T^{UE}}^{U}$	
T^1 – 5G Communication	H	M	H	L	L	M	M	H-46% M-8% L-46%
T^2 – Blockchain	M	H	M	L	H	M	L	H-46% M-8% L-46%
T^3 – Microelectronics	M	L	L	L	L	L	H	H-8% M-8% L-84%
T^4 – Quantum Computing	M	M	L	L	L	H	L	H-46% M-46% L-8%
T^5 – Digital Wallet	H	L	H	L	H	L	H	H-8% M-8% L-84%
T^6 – High-Performance Computing	H	L	L	M	L	M	L	H-46% M-8% L-46%
T^7 – Digital Twins	M	H	L	M	L	L	L	H-8% M-8% L-84%

(H – high, M – medium, L – low)

3. Interpretation of the Results and Risks of Sustainability Assessments

The interpretation of the results is based on belonging to a certain group of sustainability index intervals. The IASAM assessment methodology identifies four groups of sustainability indices (see Table I):

1) [0-0.25[- corresponds to a low level of sustainability and shows that the development of technology, according to the IASAM criteria, is unpromising.
2) [0.25-0.5[- identifies questionable prospects for technology development, with technology acceptance being a particular concern.
3) [0.5-0.75[- shows that the technology under assessment meets the IASAM sustainability criteria well enough, however, during the development of the technology, careful monitoring of impact factors must be performed.
4) [0.75 - 1] - determines the prospects for good development of the technology, however, it would be useful to repeat sometimes sustainability assessment.

Based on the grouping of the above indices, it can be stated that none of the technologies mentioned in Digital Compass 2030 are expected to fail. On the other hand, the sustainability prospects of none of these technologies are so excellent. The success of the sustainability development of 5G Communication, Digital Twins, Blockchain and Digital Wallet is not in doubt. On the other hand, the prospects for the successful development of High-Performance Computing and

Microelectronics may be hampered. Quantum Computing's development prospects are in great doubt.

The analysis of impact flows shows that there is no technology that has received the best or worst ratings in the evaluation of all flows. Each of the technologies has different advantages and disadvantages that determine their overall sustainability rating. The architecture of any technology consists of logical and physical structures, where the logical structure consists of methodology, guidelines, algorithms, rules, etc., but the physical structure is the environment for the implementation of the logical structure, that is, hardware, software, etc. [8]. In assessing digital technology, both sides of the architecture must be considered equally important.

Quantum Computing received the lowest value in the management flow assessment. This is not surprising, as theoretical advances still dominate and there is still a long way to go before an industrial solution can be found. Lack of adequate quality management and service staff can be a problem. Is there a legitimate expectation today to make a fundamental breakthrough in the development of technology that has been on the Gartner curve [4] for many years? No such justification has yet been found.

Quality flow leaders are Blockchain, Digital Wallet and Digital Twins. These technologies have long been known and tested in various applications. Quantum Computing, on the other hand, has unanswered questions about hardware, infrastructure, and the choice of specific methodologies, and, of course, the potential costs of the technology are debatable. The challenges of Microelectronics development are related to the significant expansion of the industry, which can lead to a shortage of qualified personnel and infrastructure. Production costs in the EU will be significantly higher, followed by higher final product prices. Delays in the development of 5G Communication are related to infrastructure development problems, as the subscriber's distance to the connection point must be less than in previous technologies. In addition, communication equipment is more expensive.

The socio-political and market factors that determine the Domain flow are very favourable for the development of Microelectronics and High-Performance Computing, as the market niche is quite wide, while the sustainability of Digital Wallet is successfully influenced by a strong political lobby. One might ask here why Digital Twins are so highly rated? It is a non-objectionable technology that benefits all industries, at least for as long as real AI use is not significantly represented in decision-making tasks.

The flow of Acceptance in technology sustainability assessment is fundamentally important in a democratic society, because nothing can / should happen without public acceptance and against the public interest. It is a stream that is often ignored by project developers and evaluators. In this case it is considered that all four impact flows of sustainability factors are equally important. The potentially high costs of Quantum Computing will be difficult to explain to the society, as no obvious and rapid benefits are expected within a reasonable timeframe. Will the society accept more expensive household appliances and other electronic products if they will be built using EU-made chips? This is a very challenging issue for the development of Microelectronics. In turn, respecting the heritability of technology, the society will successfully accept 5G Communications, which has already proven its viability. Various theories of conspiracy and even an objective increase in electromagnetic pollution is unlikely to affect the society opinion. Digital Twins will not have a direct impact on the citizens in the near future, but Digital Wallet technologies in various basic forms have been used successfully for several years. Blockchain acceptance is a bit more problematic because the technology increases security but consumes the time and effort of the citizens. Will the society be prepared to pay with the increased security? It depends on how sensibly and proportionately this technology will be introduced.

The above sustainability assessment of Digital Compass 2030 cutting-edge technologies is subjective and shows possible sustainability development trends of technologies. Theoretically, this subjectivity can be reduced by selecting a set of experts who could repeat the assessment. Traditional statistical processing tests can then be performed to assess the reliability of the results. Unfortunately, the subjectivity factor will not go away, because who will be the independent experts in this case and who will set up this set of experts? Will they be competent and experienced enough digital technology professionals, politicians or business people? What will be the proportions and weight of these groups in decision-making? These are questions for which the authors do not yet have a reasoned answer.

Development risk assessment (see Table II) can be considered as a partial validation of the sustainability forecast. In fact, the risks to the sustainability of technology are related to the impact of society and the external environment. The results of Bayesian modelling show that the development of Microelectronics, Digital Wallet and Digital Twins have green light and their sustainability is not threatened.

In turn, monitoring the development of sustainability is necessary for 5G Communication and Blockchain technologies, because the subjective attitude of the society will be ambiguous and polarized. However, these risks are not critical and do not jeopardize the success of these technologies.

This is difficult to explain, but similar risks are associated with the further development of High-Performance Computing.

Unfortunately, the development of Quantum Computing is the riskiest from a sustainability perspective. The assessment does not suggest that development will fail, but the risks of unexpected results are quite high.

4. Conclusion

Today, we live in a digital society in which every activity, from the provision of living conditions such as utilities, electrification, transport, healthcare and others, is based on a variety of digital technologies.

Digital technologies are a specific type of technology that is characterized by a set of interacting attributes that distinguish them from other types of technology. While Performance, Complexity, and Reliability are common to most modern technologies, the attributes of Pervasiveness, Evolutionism, and Uncertainty are special and characterize the stochastic and unpredictable effects of digital technology.

The impact of digital technologies on society is critical. Changes in the functionality of digital technologies, thanks to artificial intelligence as well as automatic self-diagnostics and reconfiguration, and prototyping capabilities, can be lightning-fast. This means that even small mistakes can have unpredictable consequences. Digital core technologies are an integral part of almost any other technology, so the balanced development of digital technologies that contribute to society's progress is important to society. This means that digital technologies must be sustainable.

In order to determine the sustainability of digital technology, acceptance must first be assessed, followed by an analysis of the quality of the technology and the flows of internal and external socio-economic factors. The flows interaction characterizes the digital technology sustainability index, which is measured in *skype* units according to the IASAM system dynamics model. The above approach allows for a self-assessment of the sustainability of new and existing digital technologies and for identifying the future prospects of each technology.

Digital technologies are characterized by Uncertainty, which is a critical attribute to the successful development of technology and poses significant risks to its sustainability. Uncertainty is mainly determined by the interaction of hidden and unanticipated factors described by the IASAM Bayesian acyclic network. The impact of potential risks determines the reliability of the technology's sustainability forecast.

The EC Digital Decade 2030 Compass identifies seven cutting-edge digital technologies / industries that will receive special attention. The selection of emerging technologies is debatable, so the authors performed a sustainability assessment and risk calculation of the nominated items.

The results of the self-assessment confirmed the sustainability of the EC Digital Decade 2030 Compass cutting-edge digital technologies, but identified some technologies whose development prospects could be problematic.

This study serves as an example of the use of the IASAM methodology, the results of which could be of interest to technology promoters and digital policy crafters.

Further research will focus on the development of the Bayesian model of unanticipated risk factors, specifying the interactions between the factors and the intensities of their effects.

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